Latest techniques in head and neck CT angiography

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Abstract: Continuous evolution of multi row CT is increasingly making CT angiography a viable imaging modality for assessment of the supraaortic and intracranial vessels as an anatomically and functionally coherent vascular system. Extended non-invasive examinations with reduced contrast volume have become feasible with the availability of 16 and 64 row MDCT scanners. Prerequisites to obtain high resolution CT angiographies of the head and neck vessels with superior detail include the administration of low contrast volume, high contrast density (400 mg I/ml) contrast media, adequate timing and data acquisition, optimal flow rate (4 ml/s) and saline flushing. Non-invasiveness, delineation of vessel calcification, virtual independence from hemodynamic conditions, and the ability to provide quantification without needing to correct for magnification are all attributes that favour CT angiography over digital subtraction angiography and to some extent even magnetic resonance angiography as an alternative non-invasive technique. CT angiography is established as a modality of choice for the assessment of patients with acute stroke and chronic steno-occlusive disease. CT angiography may indicate the presence of extra- or intracranial acute vessel occlusion and dissection, predisposing atherosclerotic steno-occlusive disease and thus indicate thrombo-embolism or local appositional thrombosis as the principle pathogenic factor. CT angiography is used to assess anatomy, and to depict the presence, location and extent of calcified and non-calcified plaque as a cause of high grade stenosis. Despite relatively limited sensitivity CT angiography is indicated for suspected or confirmed aneurysms that demand further verification of their presence, geometry, or relationship to parent artery branches and osseous anatomic landmarks. Low volume high density contrast media have substantially increased the ability of CT angiography to depict small aneurysms, small branches, and collateral vessels, and to recognize the residual lumen in vessels with high grade stenosis or conditions such as dissection or pseudo-occlusion. Superior detail high resolution CT angiography is thus a viable alternative to DSA, relegating the latter technique to endovascular treatment applications only

DOI: https://doi.org/10.1007/s00234-004-1334-8

Originally published at:
Schuknecht, B (2004). Latest techniques in head and neck CT angiography. Neuroradiology, 46(S2):s208-s213.
DOI: https://doi.org/10.1007/s00234-004-1334-8

Neuroradiology (2004) 46: S208–S213
DOI 10.1007/s00234-004-1334-8

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Latest techniques in head and neck CT angiography

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Abstract Continuous evolution of multi row CT is increasingly making CT angiography a viable imaging modality for assessment of the supraaortic and intracranial vessels as an anatomically and functionally coherent vascular system. Extended non-invasive examinations with reduced contrast volume have become feasible with the availability of 16 and 64 row MDCT scanners. Prerequisites to obtain high resolution CT angiographies of the head and neck vessels with superior detail include the administration of low contrast volume, high contrast density (400 mg I/ml) contrast media, adequate timing and data acquisition, optimal flow rate (4 ml/s) and saline flushing. Non-invasiveness, delineation of vessel calcification, virtual independence from hemodynamic conditions, and the ability to provide quantification without needing to correct for magnification are all attributes that favour CT angiography over digital subtraction angiography and to some extent even magnetic resonance angiography as an alternative non-invasive technique. CT angiography is established as a modality of choice for the assessment of patients with acute stroke and chronic steno-occlusive disease. CT angiography may indicate the presence of extra- or intracranial acute vessel occlusion and dissection, predisposing atherosclerotic steno-occlusive disease and thus indicate thrombo-embolism or local appositional thrombosis as the principle pathogenic factor. CT angiography is used to assess anatomy, and to depict the presence, location and extent of calcified and non-calcified plaque as a cause of high grade stenosis. Despite relatively limited sensitivity CT angiography is indicated for suspected or confirmed aneurysms that demand further verification of their presence, geometry, or relationship to parent artery branches and osseous anatomic landmarks. Low volume high density contrast media have substantially increased the ability of CT angiography to depict small aneurysms, small branches, and collateral vessels, and to recognize the residual lumen in vessels with high grade stenosis or conditions such as dissection or pseudo-occlusion. Superior detail high resolution CT angiography is thus a viable alternative to DSA, relegating the latter technique to endovascular treatment applications only.

Keywords Multi-slice CT angiography · Indications · High-concentration contrast media · Head and neck vessels · Arterial stenosis · Aneurysm

Introduction

The continuous development of multi-slice computed tomography (CT) technology has opened new perspectives regarding the non-invasive investigation of supra-aortic extracranial and intracranial vessels. Simultaneous acquisition of 16 to 64 slices at subsecond rotation times has made long scan ranges at high spatial resolution feasible [1]. Subsequently, extended vascular systems are depicted with markedly reduced volumes of contrast media [2]. The timing of CT data acquisition with the start of contrast injection, combined with adequate contrast flow, saline pushing and correct choice of contrast medium, are crucial to achieve the high intravascular contrast density required for high-quality CT angiograms [3]. In order to increase intravascular contrast density within the limited acquisition time of head and neck CTA, more highly concentrated contrast media (iodine 400 mg/ml) should be applied with low volumes of 40–50 ml. The objective of CTA is to depict the neck and head vessels from the aorta to the circle of Willis as an entire arterial system at examination times approximating the blood circulation time. CTA thus simultaneously depicts multiple vessels that anatomically and functionally belong together and under pathologic conditions have the potential to communicate in a variable manner. This holds true for the arterial system in patients with vessel dissection, atherosclerotic or inflammatory steno-occlusive disease, and also applies equally to the venous system intracranially. Inclusion of the aorta renders combined aortic and supra-aortic arterial disease visible [4].

Non-invasive techniques such as CTA and magnetic resonance angiography (MRA) have increasingly replaced digital subtraction angiography (DSA) in the aforementioned pathologic conditions. Unlike DSA and MRA with time-of-flight (TOF) and phase contrast (PC) techniques, CTA is independent of hemodynamic effects and is based solely on intravascular contrast density. It thus resembles k space filling in contrast enhanced fast MRA.

CTA is used to detect, localize and characterize vascular pathology in a non-invasive manner. CTA may direct treatment to a specific location and helps in defining the appropriate treatment modality.

CTA allows of the vessel wall and lumen to be assessed. With maximum intensity projection (MIP) and volume rendering (VR) techniques, vessel wall calcifications are easily recognized on CTA. While ultrasound may also give an indication of calcifications, the latter are not recognized on subtracted DSA and MRA images.

Applications of CTA

Acute cerebrovascular disease

A common indication for combined extra- and intracranial CTA is acute ischemic stroke. CTA is an integral part of a protocol, that may consist of cranial CT, perfusion CT, and CTA. In cases of early stroke (<6 h) when hemorrhage has been ruled out and morphologic signs of ischemia are absent or subtle, perfusion CT with limited amounts (30 ml) of contrast medium is of substantial help. Territorial differences in contrast transit time indicate impaired supratentorial perfusion in the area supplied by a specific major cerebral artery or its branches. CTA findings in this situation include internal carotid artery stenosis or occlusion, dissection, and thromboembolism causing obstruction of intracranial vessels. CTA will also be required when a dense artery sign is present within a major cerebral vessel either in thesupratentorial (middle cerebral, internal carotid artery) or infratentorial (vertebral, basilar artery) location. In cases of acute (<8 h) vertebro-basilar deficits, CTA is performed – without prior perfusion CTA – in order to assess the patency of the extra- and intracranial vertebral arteries and the basilar artery.

Pathophysiologically, CTA may provide clues as to thromboembolism as the principle mechanism of intracranial artery obstruction or recognize pre-existing intracranial stenosis with subsequent appositional thrombus formation. CTA may specify the indication for systemic intravenous fibrinolysis or local intraarterial thrombolysis. In the latter situation, CTA allows treatment to be directed to the artery involved and specifies the vessel segment affected by thrombosis or thromboembolism. CTA may delineate the extent of vessel occlusion to better advantage in DSA. This is due to the fact that CTA is virtually independent of the local hemodynamic conditions and is unaffected by contrast dilution which plays a role in DSA when extensive leptomeningeal collaterals are present.

In the setting of acute stroke, CTA may be preferred over MRA because it supplements the preceding CT examination. It is less time consuming and less susceptible to motion artifacts in critically ill patients. Following treatment non-invasive follow-up examinations with CTA may reveal patency of the vessel or persistence of the arterial obstruction. The concomitant CT examination provides clues as to the presence and extent of an ischemic infarction, potential hemorrhagic transformation or mass effect.

Limitations of CTA include recognition of the vessel wall hematoma in the subacute stage of vessel dissection. This is recognized to better advantage by MR imaging and TOF MRA. A further limitation is the detection of distal branch occlusions of the main intra-arterial arteries.

Chronic cerebrovascular disease

CTA is able to depict the location and extent of high grade vessel stenosis (>70%) following colour Doppler ultrasound as a screening technique. Compared to ultrasound, CTA and MRA are markedly less dependent on the experience of the investigator. Among the reconstruction techniques, the degree of stenosis as well as the extent of calcifications best delineated by VR [5]. CTA is more precise than MRA in delineating the residual lumen in vessels with high- degree stenosis. MRA commonly overestimates high grade stenoses due to turbulent flow.

Despite its alleged role as the "gold" standard, DSA is much more dependent on adequate delineation of the "profile" of the stenosis than CTA [6]. By interactive rotation, CTA as well as MRA allow an ideal projection of the maximum degree of stenosis to be displayed. The latter is of particular importance in eccentric stenoses. Rotational DSA has meanwhile also contributed to overcoming these limitations. However, before performing (rotational) DSA in patients intended to be treated endovascularly, the optimal "working" projection may already be anticipated based on CTA projections.

Limitations of CTA include extracranial stenoses with semi- or circumferential calcifications that impair estimation of the degree of stenosis [7]. Due to the proximity to dense bone or to the contrast-filled cavernous sinus, the petrous and cavernous segment of the internal carotid artery are difficult to assess. Patients with renal insufficiency or markedly reduced cardiac function, as well as uncooperative patients are candidates for CTA in only exceptional circumstances.

Findings in patients with chronic cerebrovascular disease include vessel wall arteriosclerosis, arterial ectasia and elongation, stenosis, or occlusion.

High intravascular contrast density as provided by contrast media with 400 mg iodine per milliliter provides improved visualization of the vessel lumen in patients with high grade stenosis or conditions such as internal carotid artery pseudo-occlusion. Collateral pathways between the external carotid and vertebral arteries are well delineated (Fig. 1). Luminal changes such as deep ulcerations and areas of repetitive stenosis are delineated to better advantage by CTA compared to flow-dependent DSA (Fig. 2) and MRA techniques.

Treatment planning for extracranial stent-assisted percutaneous transluminal angioplasty is facilitated by CTA. CTA depicts the (circumferential) degree and longitudinal extent of calcification accompanying the stenosis, demonstratespotential irregularity within the vessel lumen and delineates the vascular anatomy proximal and distal to the stenosis. Intracranial collaterals via the circle of Willis are also demonstrated.

These factors provide an estimate of the ease or difficulty of endovascular access to the stenosis and the passage of the residual lumen by guidewires or protection systems. The degree of calcification and its circumferential arrangement allow the resistance to the balloon dilatation procedure itself to be anticipated. Pre-interventional planning is facilitated based on MIP and VR CTA images of the carotid bifurcation.

A particular advantage is the ability to perform measurements of the vessel diameters proximal and distal to the stenosis. These allow the optimal stent and balloon dimensions to be determined precisely without the need to correct for magnification. Following deposition of the stent and dilatation, CTA is only rarely required. The limited ability of CTA to depict the vessel lumen within the stent and the compromise of MRA by stent-induced artefacts render Doppler ultrasound the modality of choice for performing short- and long-term follow-up examinations.

Extra- and intracranial aneurysms

Long-term sequelae of carotid or vertebral artery dissection includes pseudoaneurysm formation. CTA is able to detect these lesions along the extracranial carotid artery. Recurrent emboli or a concomitant high grade stenosis of the parent vessel may represent an indication for treatment. The protocol consists of CTA from the aortic arch to the circle of Willis to include the anatomic collat-

Fig. 1 Supra-aortic CT angiography of a 69-year-old patient with recurrent episodes of left transient ischemic attacks. CTA (40 ml Iomeron 400) depicts right common and internal carotid artery occlusion. Collateral filling of the external carotid artery is via the right vertebral artery. The left internal carotid artery is narrowed distal to an ulceration and a calcified plaque at the origin. Additionally a stenosis is present within the cervical segment of the left vertebral artery

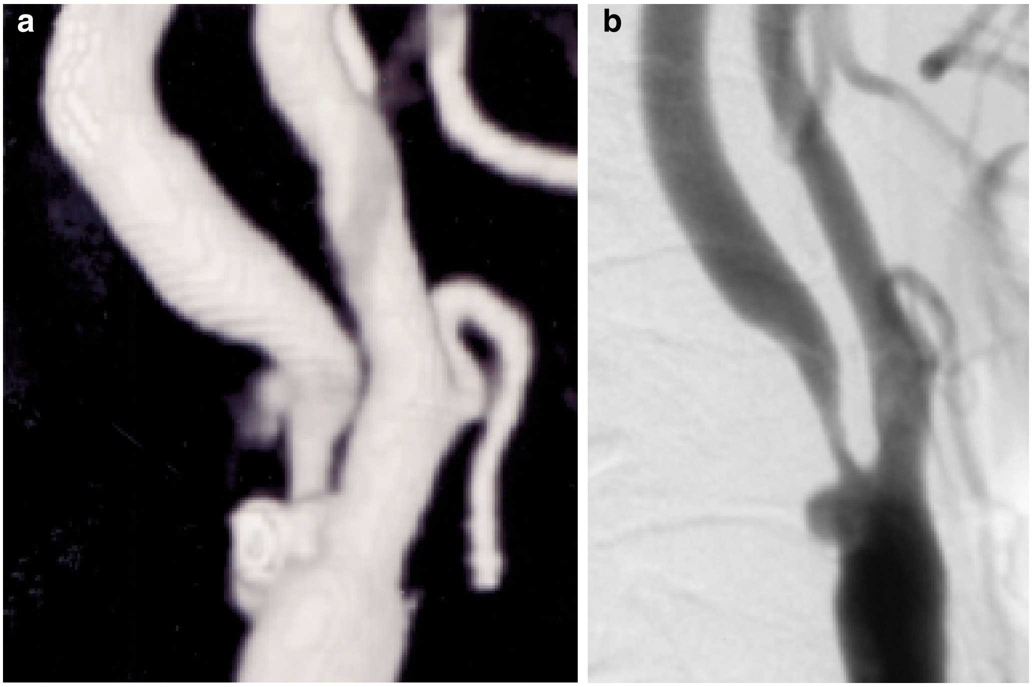

Fig. 2a,b Volume rendering targeted CTA reconstruction of right carotid bifurcation (**a**) and corresponding lateral projection DSA (**b**) in a patient with amaurosis fugax. CTA depicts a high degree stenosis and a deep proximal ulceration corresponding in location to the DSA. CTA (40 ml of contrast 400 mg I/ml) depicts markedly more irregularity of the proximal ulceration than DSA. A second ulceration at the distal end of the noncalcified plaque is not visible on DSA performed with an interval of 3 days

erals. Visualization of the collaterals is important in case treatment of the pseudoaneurysm is intended. The potential higher spatial resolution renders CT angiography superior to MRA in the recognition of concomitant vessel stenosis. However, limitations of CTA include (rare) vertebral artery pseudoaneurysms.

Intracranial aneurysms are true aneurysms. Located along the intradural internal carotid artery and the proximal bifurcation of cerebral vessels, aneurysms usually present with subarachnoid hemorrhage and rarely with cranial nerve palsy. The protocol consists of CTA from the foramen magnum to an area 6 cm above the sella floor to include infratentorial and pericallosal aneurysms. In both circumstances CTA focussed on the intracranial circulation may be performed in order to detect and localize the source of bleeding [8]. The sensitivity of detecting a single aneurysm or multiple aneurysms is highest for DSA. It is therefore imperative to perform DSA on every patient with subarachnoid hemorrhage and to add CTA in cases where the configuration of the aneurysm or its relationship to anatomic landmarks require specification. CTA is well suited to reveal the 3D geometry of aneurysms and delineate the relationship between the base of the aneurysm and the origin of major branches (Fig. 3). Additionally, CTA may be used for neuronavigation in order to plan the craniotomy and guide the approach to the aneurysm [9]. Postoperative CTA examinations have become feasible with the availability of titanium clips.

Large aneurysms require MIP reconstruction on CTA rather than surface rendering in order to distinguish the aneurysm from the skull base. At times, CTA may be the best technique to confirm an aneurysm suspected at DSA.

In patients in whom contrast-enhanced CT raises the suspicion of an incidental aneurysm, CTA is added in order to confirm the finding and to determine whether the aneurysm is suited for endovascular treatment. Multislice CT has been found to be superior to single-slice CT [10]. Screening in patients who are prone to harbor or develop intracranial aneurysms is usually performed by MRA in order to avoid radiation exposure.

Miscellaneous vascular lesions

An additional indications for assessment of the supra-aortic extra-and intracranial vessels with CTA is trauma to the neck potentially resulting in vessel dissection or laceration. Further indications include preoperative or postoperative evaluation of patients undergoing extra- or intracranial bypass operations or patients with external carotid artery anastomosed flaps to cover tissue defects following resection of neoplasms of the neck.

Intracranial dural venous sinus thrombosis is well recognized at CTA covering the intracranial vessels from the skull base to the vertex. MIP and VR reconstructions depict the presence and extent of dural sinus thrombosis and provide the basis for follow-up examinations in order to monitor treatment effects. Recanalization of segments or entire dural sinuses is well delineated. CTA is as sensitive as for recognition of dural sinus thrombosis, but is less sensitive in identification of internal cerebral vein and convexity vein thrombosis. Compared to MRA, the examination is less time consuming and is feasible in patients under intensive care monitoring conditions without particular precautions.

Limitations of CTA consist of a variety of vascular lesions that are either in close proximity to bone such as dural arteriovenous fistulae or require high temporal resolution. Recognition of an arteriovenous malformation (AVM) as a cause of bleeding is feasible with CTA unless a small lesion is entirely compressed by an adjacent hematoma. These limitations also apply to MRA and DSA in ruptured micro-AVMs. In large AVMs, MRA and DSA are significantly superior for lesion characterisation and for recognition of intranidal aneurysms and/or venous constriction as potentially predisposing to hemorrhage.

Spinal vascular lesions such as dural or AVMs pose the same problems for CTA as their intracranial counterparts. However, adequate delineation of these vascular lesions is limited by their proximity to bone and intradural and epidural venous plexuses.

Role of contrast agents

Multi-row CTA permits extended vascular investigations with low contrast volume at acquisition times that closely approach the blood circulation time. Intravascular contrast is determined by and is proportional to the rate of intravenous iodine administration. Arterial contrast density additionally depends on iodine concentration and injection time.

Administration of more highly concentrated contrast media permits high injection rates to be avoided.

In our protocol, a contrast agent with high iodine concentration (iomeprol 400, Iomeron, Bracco) compared favorably to a contrast agent with standard 300 mg I/ml concentration. Interindividual differences in vascular opacification were reduced when the contrast medium volume was adjusted to body weight. With the principle parameters such as contrast volume (40–50 ml), injection rate (4 ml/s), and table feed kept constant, administration of the more highly concentrated contrast medium proved significantly superior for delineation of intracranial vessels, collaterals at the circle of Willis, and extracranial pathologies like high grade stenosis, pseudo-occlusion, vessel dissection, and pseudoaneurysm formation. Small external carotid arteries used for bypass operations or microanastomes were also delineated to better advantage by the more highly concentrated contrast agent. High intravascular contrast aided in the delineation of particular anatomic locations such as the petrous segment of the internal carotid artery and the cervical segment of the vertebral artery.

When pathologic conditions prevail, optimal intra-arterial contrast is required to accurately depict the residual lumen as is in the case in segments of high grade stenosis. Insufficient intravascular contrast may have significant consequences as it may cause the degree of stenosis to be overestimated or misinterpreted as occlusion.

Highly concentrated contrast media do not cause side effects. Warming of the contrast medium to body temperature aids in proper application. Careful patient selection with respect to renal function, allergy disposition, and thyroid function (as in any intravascular contrast examination) is mandatory.

With these precautions, CTA has become a frequently requested non-invasive examination that covers a broad range of indications. Highly concentrated contrast media play an essential role in obtaining more detailed,

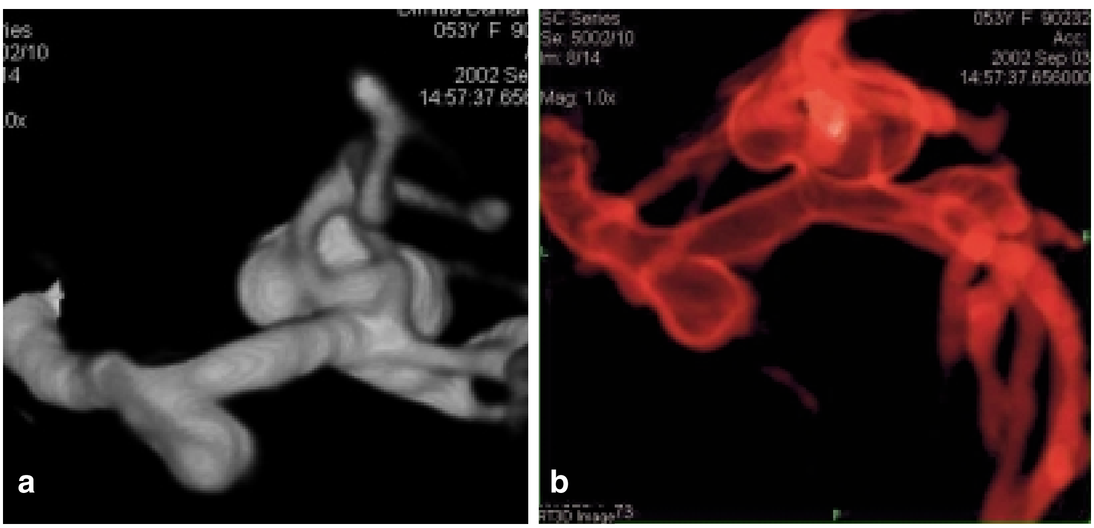

Fig. 3a,b Volume rendering targeted CTA of two aneurysms arising from the internal carotid artery (**a**) and the middle cerebral artery bifurcation (**b**). The location, configuration, and relationship to the parent arteries and adjacent branches is well delineated. CTA with 30 ml contrast 400 mg I/ml high-resolution CT angiograms. CTA partially replace DSA as a diagnostic modality. Specifically, CTA angiography restricts the indications for DSA to those patients undergoing endovascular treatment following prior non-invasive evaluation.

Technique

Table 1 describes our examination protocol for an extra- and intracranial examination of neck and head vessels for a 16-row CT scanner (Siemens Sensation 16). The initiation of the scan is based on the care bolus technique with a threshold of 80 HU within the aortic arch. A new protocol for a 64-row CT scanner from the same manufacturer is under current investigation.

Table 1 Examination protocol for multislice CT of the head and neck

Scan range: aortic arch - circle of willis (caudo-cephalad coverage)
Collimation/slice reconstruction: 16×0.75/ 0.75/0.5mm increment
Table feed/ rotation time: 18 mm (= pitch 1.5) /0.5 s
Contrast medium: 40 ml (<80 kg), 50 ml >80 kg
Iodine concentration: 400 mg/ml Iomeron 400 Bracco
Flow rate: 4 ml/s
Flushing: 20 ml saline art flow rate 4 ml/s

Future perspectives

With the availability of 64-row CT the potential of CTA to further improve delineation of the head and neck vascular system is increased. Future perspectives for CTA are targeted to better characterization and comprehension of vessels that are distal to the major vessels amenable to CTA investigation currently. Improved spatial and temporal resolution with 64-row CTA will allow assessment of those central nervous system vessels that consist of small arteries supplying the brain and the soft tissue in the head and neck area. Further reduction of contrast volume will also become feasible. Functional studies with separate assessment of arterial and venous phases will also become feasible. The objective is to render visible those types of lesions that currently pose limitations, such as dural fistulae, vasospasm or arteritis, and leptomeningeal collaterals.

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